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**September 05, 2003**

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**FILING DATE:** *July 22, 2002*
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07/22/02 JC784 U.S. PTO

11036 U.S. PTO 60/397941

# PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

**Express Mail Label No.** EV 073381543 US

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☑ *Additional inventors are being named on the* 1 *separately numbered sheets attached hereto*

**TITLE OF THE INVENTION (500 characters max)**

METHOD FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE

*Direct all correspondence to:* **CORRESPONDENCE ADDRESS**

☐ Customer Number ______ *Type Customer Number here* → *Place Customer Number Bar Code Label here*

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**ENCLOSED APPLICATION PARTS** *(check all that apply)*

- ☑ Specification *Number of Pages* 6
- ☑ Drawing(s) *Number of Sheets* 4
- ☑ Application Data Sheet. See 37 CFR 1.76
- ☐ CD(s), Number ______
- ☑ Other (specify) RETURN RECEIPT POSTCARD

**METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT**

- ☑ Applicant claims small entity status. See 37 CFR 1.27.
- ☑ A check or money order is enclosed to cover the filing fees
- ☐ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: ______
- ☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($): $80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

- ☑ No
- ☐ Yes, the name of the U S. Government agency and the Government contract number are ______

*Respectfully submitted,*

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Docket Number: ______

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## USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT



[redacted]

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# *PROVISIONAL APPLICATION COVER SHEET*

*Additional Page*

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Number 2 of 2

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60397941 .072202

## Application Data Sheet

### Application Information

Application Type:: Provisional
Subject Matter:: Utility
Suggested classification::
Suggested Group Art Unit::
CD-ROM or CD-R?::
Number of CD disks::
Number of copies of CDs::
Sequence submission?::
Computer Readable Form (CRF)?::
Number of copies of CRF::
Title:: Method for Electropolishing Metal Film on Substrate
Attorney Docket Number::
Request for Early Publication?::
Request for Non-Publication?::
Suggested Drawing Figure::
Total Drawing Sheets:: 4
Small Entity?:: Yes
Petition included?::
Petition Type::

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**Domestic Priority Information**

| Application:: | Continuity Type:: | Parent Application:: | Parent Filing Date:: |
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**Foreign Priority Information**

| Country:: | Application number:: | Filing Date:: | Priority Claimed:: |
|---|---|---|---|
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# METHOD FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE

Objectives:

This present invention relates generally to a method to provide better and precise control of the end point detection in electropolishing.

Descriptions:

**Fig. 1** shows one embodiment of nozzle plate for wafer electropolishing module which was previously disclosed in U.S. Patent No. 6,248,222 B1, entitled METHODS AND APPARTUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, dated June 19, 2001, and Provisional Application Serial No. 60/372, 566, entitled METHOD AND APPARATUS FOR ELECTROPOLISHING AND/OR ELECTROPLATING, filed on April 14, 2002, the entire content of which are incorporated herein by reference.

As shown in **Fig. 1**, nozzle plate **1004** can include nozzles **1008, 1010** and end-point detector **1006**.

For a more detailed discussion of end point detection, see U.S. Patent Serial No. 09/570,566, entitled METHOD AND APPARATUS FOR END-POINT DETECTION, filed on May 12, 2000, which is incorporated in its entirety by reference herein.

Wafers from the same deposition recipe will generally have a similar metal film thickness profile and consequently can be polished using a similar polishing recipe. A recipe can consist of liquid flow rate, current or voltage set-point, center-to-edge distance, initial rotational speed, polishing duration, center polishing rotational speed, nozzle type, current or voltage table, bulk ratio table for constant current, and repetition setting.

Typically, before wafers **1002** are polished in accordance with the present invention, a substrate thickness metrology tool will measure and map the thickness of the film deposited on said wafers. The measurements can consist of radius, theta, and relative thickness of the fixed locations. As shown in **Fig. 2A**, the metrology tool can measure multiple fixed locations **2010** to map the relative thickness of wafer **1002**.

<u>Polish the Top Portion of Copper Layer</u>.

As nozzle **1008** or **1010** is at position **2022** (x, y), the present invention will reference the thickness measurement data based on points closest to **2022** (x, y). As shown in **Figs. 2A, 2B** and **2C**, a particular embodiment of a substrate thickness at point **2022** (x, y) can be interpolated based on four-points locations **2012** ($x_i$, $y_{j+1}$), **2014** ($x_{i+1}$, $y_{j+1}$), **2016** ($x_{i+1}$, $y_j$), **2018** ($x_i$, $y_j$). The thickness of film at location **2022** (x, y) can be as assumed as:

$$T = Ax+By+Cxy+D \qquad (1)$$

where the interpolate value thickness T at (x, y) from the following four known points is:

$T_{i,j}$ at $(x_i, y_j)$ $\quad$ $T_{i,j}+1$ at $(x_i, y_{j+1})$

$T_{i+1,j}$ at $(x_{i+1}, yj)$ $\quad$ $T_{i+1,j+1}$ at $(x_{i+1}, y_{j+1})$

$$T_{i,j} = Ax_i + By_j + Cx_iy_i + D \qquad (2)$$

$$T_{i,j+1} = Ax_i + By_{j+1} + Cx_iy_{j+1} + D \qquad (3)$$

$$T_{i+1,j} = Ax_{i+1} + By_j + Cx_{i+1}y_j + D \qquad (4)$$

$$T_{i+1,j+1} = Ax_{i+1} + By_{j+1} + C \qquad (5)$$

The values of A, B, C, and D can be obtained by solving above four equations.



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$$C = (T_{i,j} - T_{i,j+1} - T_{i+1,j} + T_{i+1,j+1}) / [(x_i - x_{i+1}) * (y_j - y_{j+1})]$$
$$B = (T_{i,j} - T_{i,j+1}) / (y_j - y_{j+1}) - x_i * D$$
$$A = (T_{i,j} - T_{i+1,j}) / (x_i - x_{i+1}) - y_j * D$$
$$D = T_{i,j} - x_i * B - y_i * [(T_{i,j} - T_{i,j+1}) / (y_j - y_{j+1})]$$

For more accurate interpolation:

$$T = Ax^2 + By^2 + Cxy + Dx + Ey + F \qquad \textbf{(6)}$$

where the Thickness T at (x, y) can be interpolated using six points closest 2022 (x, y) and the constants A, B, C, D, E and F can be obtained by solving the six equations above.

After thickness metal film is calculated by using formula (1) or (6), then computer will calculate the polishing current I based on the thickness as follows:

$$I = k\,T\,(x, y) \qquad \textbf{(7)}$$

where k is the factor related to polishing rate.

Then computer will send new set point of the polishing current to polishing power supply to perform metal polishing process.

Even in the best of computing environment, there will be delay $\Delta t$ from the time when above calculation is done to the time when the polishing power supply sent new polishing current to nozzle to polishing 2022 (x, y). As such the present invention use the delay time $\Delta t$ as offset time, i.e. at the time $\Delta t$ before nozzle reaches the point 2022, computer start to calculate the process for point 2022. By this way, the right polishing current for point 2022 will be provided on nozzle just when the nozzle reaches point 2022.

Polish the Remaining Portion of Copper Layer.

After the top portion of copper is removed, more specifically speaking, after remaining metal thickness reaches less than 1000 Å, end-point detector **1006** scans and records the reflectivity of wafer **1002**, then metal thickness can be calculated by the following formula:

$$T(x, y) = p(T) * R(x, y) \qquad \textbf{(8)}$$

where R (x, y) is the reflectivity of metal film at position **2022** (x, y) measured by end point detector **1006**, and p (T) is the conversion factor of reflectivity to thickness, which itself is a function of thickness. p (T) can be measured by using a set of metal film with different thickness, and then store into computer in a form of look-up table. By this way, the thickness T (x, y) can be determined based on look-up table and measured reflectivity. The thickness matrix will be stored in computer memory as follows:

$$\begin{array}{l} T_{1,1}\ T_{1,2}\ T_{1,3}\ \ldots\ T_{1,m} \\ T_{2,1}\ T_{2,2}\ T_{2,3}\ \ldots\ T_{2,m} \\ T_{3,1}\ T_{3,2}\ T_{3,3}\ \ldots\ T_{3,m} \\ \ldots\ldots \\ T_{n,1}\ T_{n,2}\ T_{n,3}\ ..\ T_{n,m} \end{array}$$

Use the similar method as described earlier, the thickness of metal film at any location can be calculated by using formula **(1)** or **(6)**. Also used in the same way as described before, the polishing current can calculate by using formula **(7)**.

The process is repeated until the reflectivity recorded by end-point detector **1006** is within a pre-set range for the device wafer. It should be mentioned that the pre-set range of reflectivity depends on metal pattern density, and over-polishing range. Usually, the less patterned density, the lower pre-set of reflectivity. Also, the preset reflectivity can vary based on pattern density. As previously disclosed in U.S. Patent Application No. 09/570,566, entitled METHOD AND APPARATUS FOR END-POINT DETECTION,

filed on May 12, 2000, the entire content of which is incorporated herein by reference, the preset reflectivity can be calculated based on pattern density of mask or measured by one polished wafer with minimum metal recess.

As shown in **Fig. 3**, the control system **3002** that performs the recipe, record the reflectivity, and update the metal film thickness profile will be required to handle the same sets of tasks for one or more wafer electro-polishing modules **3004** simultaneously. The processing and computing load required can slow down the response time for read-outs, electrical output and mechanical motion. More loads it requires to handle, the slower the completion time for each load.

For example, during the time it requires for the control system **3002** to adjust the current or voltage to nozzle **1008** or **1010** based on the last reflectivity recorded by the end-point detector **1006**, wafer **1002** has rotated and moved further away from the original location of the recorded reflectivity, or wafer **1002** is polished for a longer increment as the result of a longer response time required for the adjustment.

In the present exemplary embodiment, distributed sub-control system arrangements is added to the single control system platform and offload the task-oriented functions to individual sub systems, such as a motion server block controller. With reference now to **Fig. 4**, one sub-control system **4006** will be dedicated to one process chamber, such as wafer electro-polishing module **4008**.

The distributive sub system arrangement will automatically solve the problem of the time lagged during polishing process application in a single control system computing. A PC based control system **4002** receives and sends data to each of the sub-control systems **4006** using a device-to-device transmission media **4004** such as RS-485 or DeviceNet.

For example, each sub-control system **4006** will perform same set of tasks for its wafer electro-polishing module **4008**. As depicted in **Fig. 4**, sub-control system 1 will be dedicated to operate the chuck, motor drives, nozzles and end-point detector and to

process the data for digital IO and analog IO for process chamber **1**. Simultaneously, the other sub-control systems **2** and **3** will be dedicated to the respective process module for electro-polishing.

Under the distributive arrangement, each sub-control system **4006** will be able to exert better and finer control in both mechanical and electrical performance, i.e., to record both rotational angel and location of wafer **1002** with remaining copper layer and to control nozzle functions based on the reflectivity recorded for the given location in 4 milliseconds or better. Since each sub control system **4006** has sufficient processing capacity, the present exemplary invention can add or extrapolate other values or tables in the recipe based on the reflectivity data to achieve finer control of the polishing.

Moreover, as the result of distributing processing requirement of the wafer electro-polishing to each sub control system **4006**, the control system **4002** and the sub control system **4006** will have more available processing power to operate or perform other tasks. In particular, the present invention will make it possible for additional tools and/or applications to be added to the polishing process without diminishing the speed or practicality of such tool configuration. For example, an inline metrology tool can be added to measure the profile of each wafer before said wafer is loaded to the wafer electro-polishing module. The inline metrology tool measures the thickness of metal layer on wafer **1002** for the sub control system **4006** (or control system **4008**) to determine the required current output to achieve a flat uniform copper surface. Sub control system **4006** (or control system **4008**) then generates a new table with data such as the distance versus current rate times user defined set-points.

Although the present invention has been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

Title: METHOD FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE
Inventor: Hui WANG et al.
Filed: Herewith


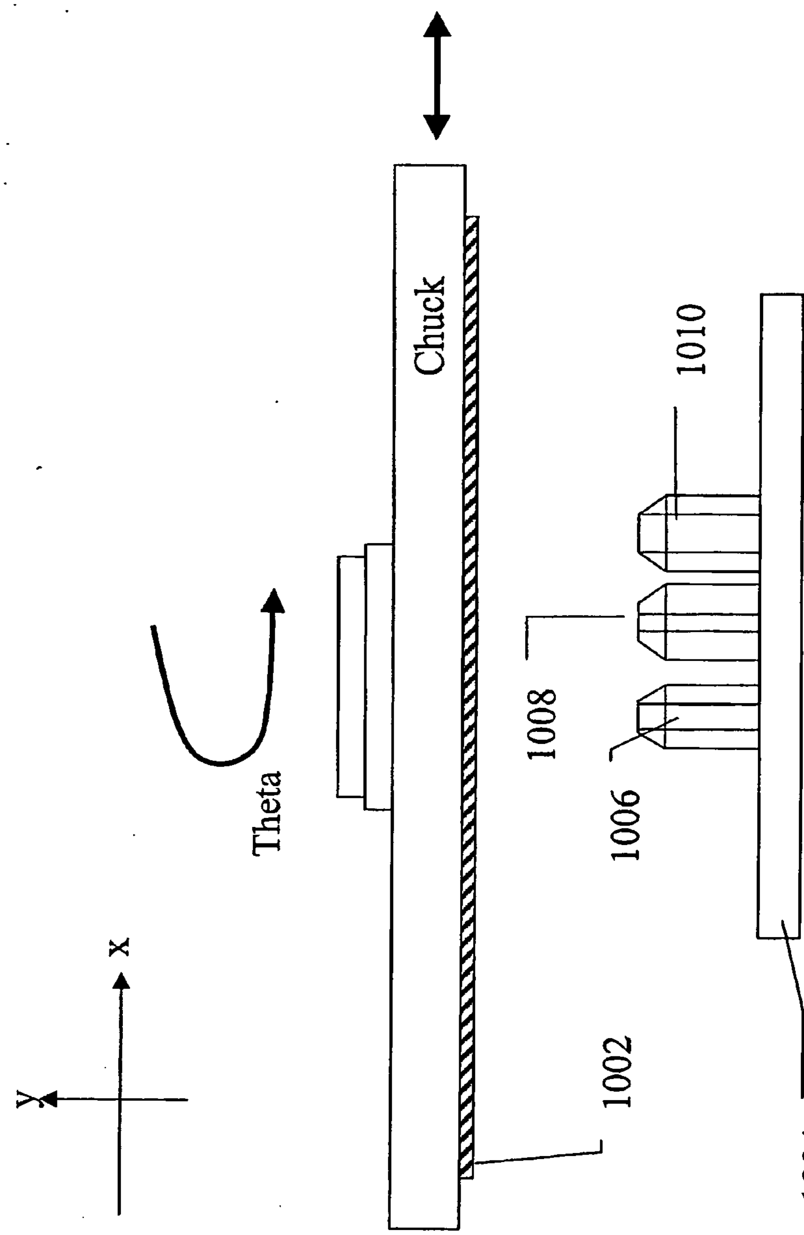


Fig. 1 – Nozzle Plate

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Inventor: Hui WANG et al.
Filed: Herewith
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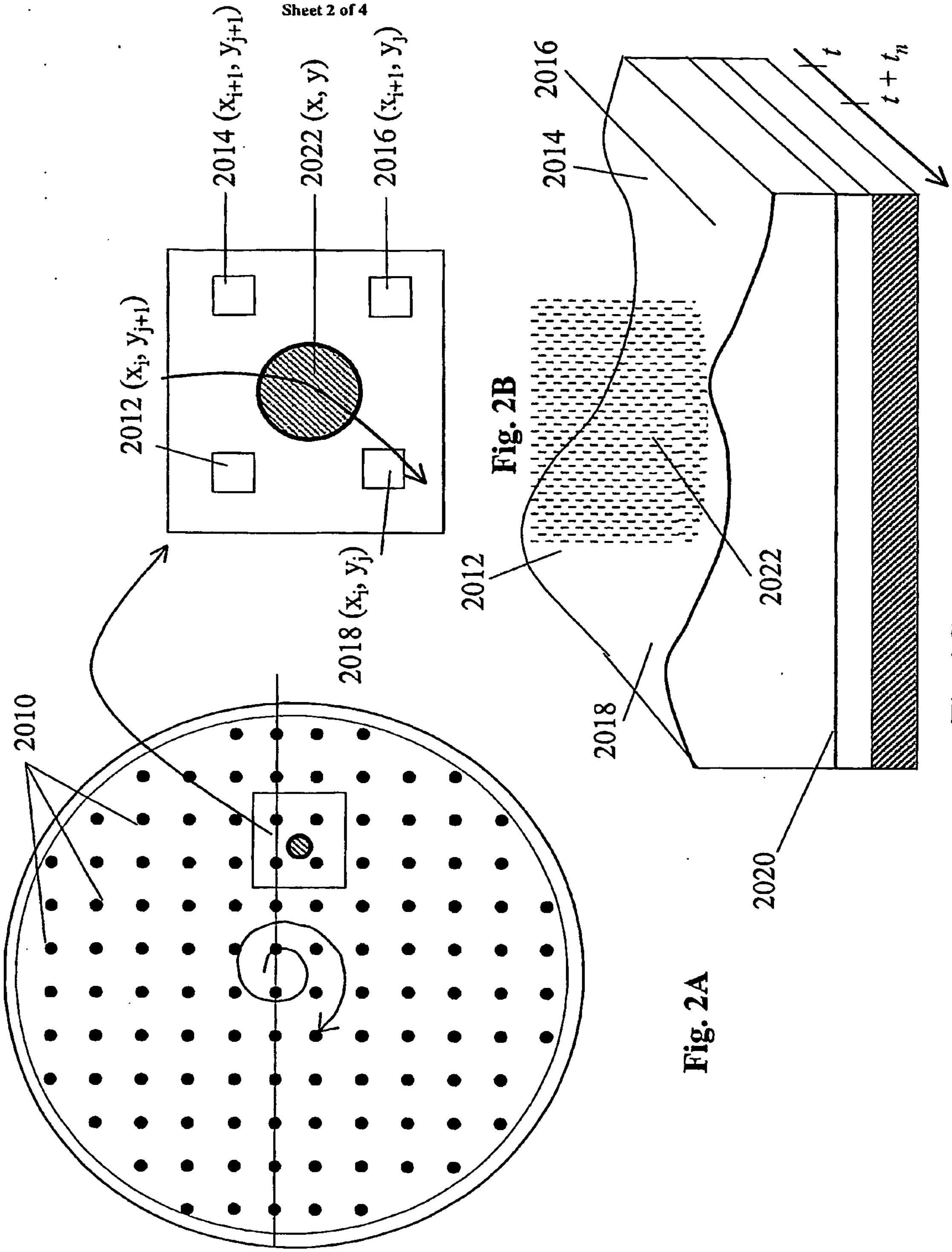


Fig. 2A

Fig. 2B

Fig. 2C

**Title: METHOD FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE**
**Inventor: Hui WANG et al.**
**Filed: Herewith**
**Sheet 3 of 4**

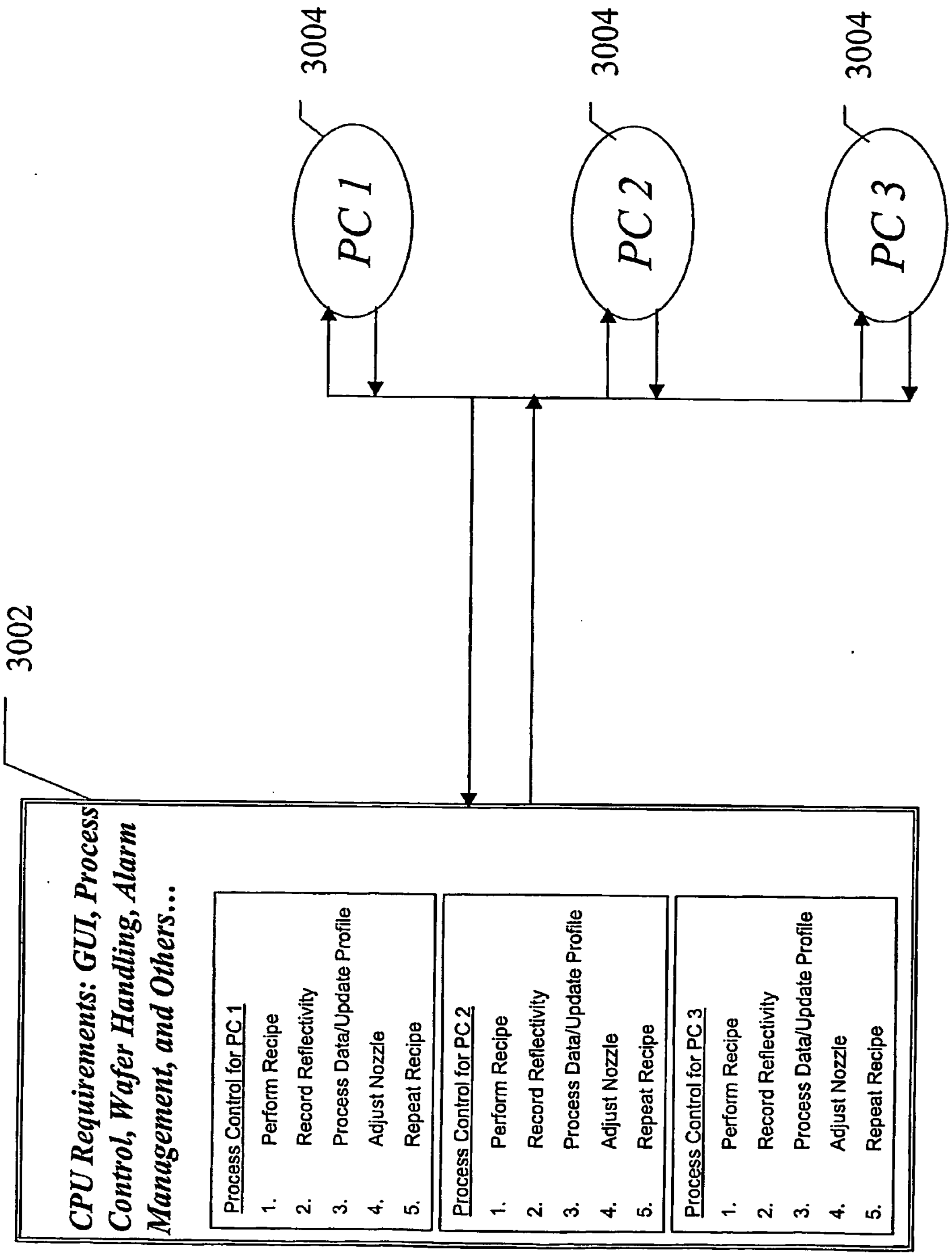


**Fig. 3 – Single Control System Platform**

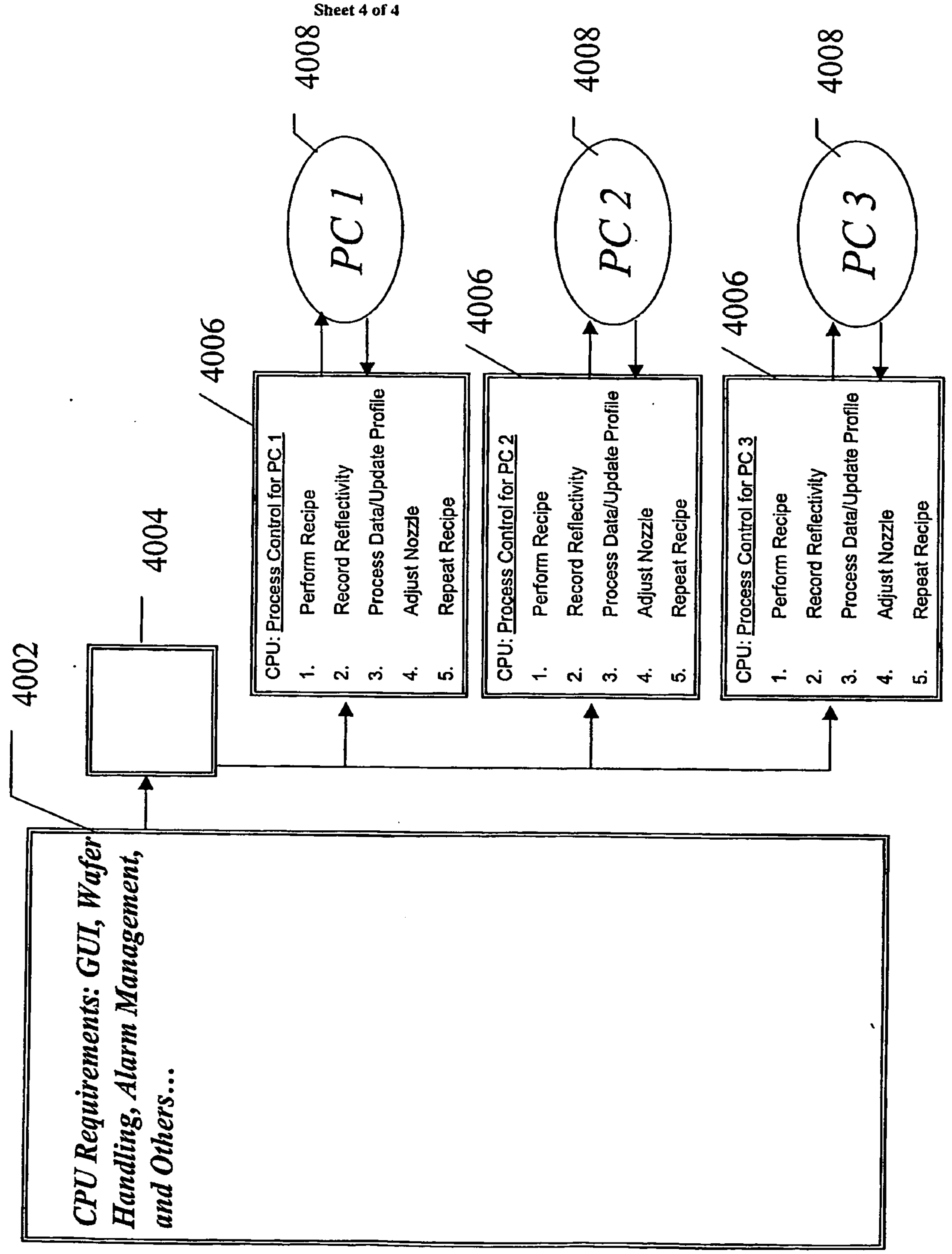


Fig. 4 – Distributed Sub-Control System

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*